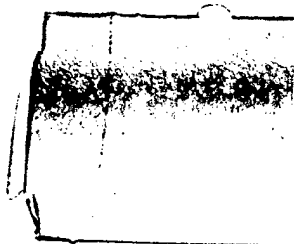


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GROWTH OF THE PHYSICS OF METALS AND PHYSICAL METALLOGRAPHY  
IN THE CHINESE PEOPLE'S REPUBLICS FOR 10 YEARS

- USSR -

by Chou Chih-Hung, K'uo Tsung and Ching Ling-Chao

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## GROWTH OF THE PHYSICS OF METALS AND PHYSICAL METALLOGRAPHY IN THE CHINESE PEOPLE'S REPUBLICS FOR 10 YEARS

[This is a translation of an article written by Chou Chih-hung, K'uo Tsung and Ching Ling-chao in Fizika Metallov i Metallovedeniye (Physics of Metals and Metallography), Vol VIII, No 6, 1959, pages 820-828.]

The physics of metals and metallography have made great strides in China since the formation of the Chinese People's Republic in 1949.

Prior to the Liberation only a few scientific workers in China were concerned with the electron theory of metals and the statistical theory of the ordering of solid solutions.

Now, under the guidance of the Chinese Communist Party, research work in various fields has been expanded and much has been accomplished, especially after the Great Leap Forward in 1958.

The present article attempts at surveying briefly the activities in China during the last ten years.

During the Period of the Reconstruction of the National Economy and the initial period of the First Five-Year Plan the attention of the Chinese metals physicists and metallographers has been focused mainly on rearing cadres of scientific research workers and solving the everyday problems of industry.

Major scientific researches were commenced only since the years 1954-1955. For convenience, these researches can be grouped as follows:

1. Physics of strength and plastic flow
2. Internal friction and diffusion
3. Phase transitions
4. Theory of metals and alloys.

### 1. Physics of the Strength and Plastic Flow of Metals

Most of the research done in this field has pertained to the problem of devising alloys for service at high temperatures. The efforts of the entire collective of the Department of the Physics of Metals at Gilin University were centered on investigating various properties of a number of ferritic tungsten steels (Bibl. 1), inclusive of physical properties, resistance to oxidation, fatigue, wear and erosion. These studies demonstrated that the addition of three to five percent of tungsten to steel increases its shear

moduli, especially at high temperatures. Kou Chen-chuan and his co-workers (Bibl. 2) found that the activation energy of viscous flow on grain boundaries in iron increases when tungsten is added as an alloying element. This series of studies was initiated by M. G. Morozov, who worked as consultant to the University's Department of the Physics of Metals in 1956-1958. Broader research work in the same direction was also commenced in other scientific research institutions, for the purpose of seeking out the optimal compositions of high-temperature ferritic steels with practical applications.

Attempting to devise new high-temperature austenitic steels, the scientific research workers of the Department of the Physics of Metals at Peking Institute of Ferrous Metallurgy and in other research institutes investigated the effect of other alloying elements on the high-temperature properties of austenitic manganese chrome steels.

The effect of the  $\delta$ -phase in 18-8 type stainless steel with three percent of molybdenum and one percent of titanium was investigated by Li Yo-ko and Chuang Yu-chi (Bibl. 3), who observed that the presence of the  $\delta$ -phase reduces the creep resistance of steel at 560 to 680 Centigrade degrees.

Ke Ting-sui and Kung Chin-pin (Bibl. 4) investigated, by the torsion pendulum method, the effect of carbon on creep along grain boundaries in iron, and observed that carbon traces of order 0.00004 percent increase the creep resistance of iron, in which connection this effect grows with increasing carbon content. These results were interpreted from the standpoint of the theory of grain-boundary structure advanced by Ke.

Tsien Lin-chao, Hou Shou-an and Yang Ta-yu (Bibl. 5-7) carried out electronmicroscopic studies of the process of slippage in single crystals. It was observed that in a single crystal of aluminum of the technical purity the magnitude of the strain related to every slip line is comparatively great and that slip lines consist of layers with a relative displacement of order 200 and 2,000 angstroms in a single specimen.

The same investigators had also studied the effect of a prior local strain on the plastic flowage of single crystals of aluminum. Tsien Lin-chao, Yang Ta-yu and L. I. Vasil'yev (Bibl. 8) (the latter was consultant to the Department of the Physics of Metallic State at Peking University and now is working at Tomsk State University), on having established the effect of the strain at some fixed temperature on the development of slip lines at another temperature, showed that there does not exist any mechanical equation of state in metals.

They found that a prior strain at minus 180 Centigrade degrees, accompanied by straining at higher temperatures, gives birth to wavy slip lines consisting of parallel segments of slip

lines joined by connecting segments which upon careful study proved to consist of groups of parallel fine slip lines, curved slip lines or transverse slips.

The investigators suggested that strain in the connecting segments ensues as a result of a concentration of stresses when two series of parallel slip lines approach each other in the course of their development.

Also investigated was the effect of ordering and impurities on plastic flow. The researches of the Department of the Physics of Metals at Peking University (Bibl. 9) investigated the effect of ordering on plastic flow in polycrystalline  $\text{Cu}_3\text{Au}$  and showed that at a strain rate of one millimeter an hour a disordered alloy displays a sawtooth tension curve at room temperature, similar to the tension curve of soft steel in the range of blue brittleness. Tsien Lin-chao and Liu Min-chi (Bibl. 10) observed that impurities in tin strongly curtail the magnitude of microcreep and cause the strengthening related to the process of microcreep; the specimens cannot recover their original characteristics by resting for several hours after their microcreep tests as distinguished from the case of the tin refined by zone smelting or the high-purity zinc previously obtained by Chalmers (Bibl. 11).

Ke Ting-sui and his co-workers (Bibl. 12) observed that internal friction in strained iron, copper and aluminum increases abruptly directly before their elastic limit is reached; on the other hand, when an explicitly expressed yield point exists, as in low-carbon iron, internal friction remains constant during the process of stretching.

Investigations were also extended (Bibl. 13) to the effect of the rate of strain and annealing after straining at room temperature or at high temperatures on internal friction in strained copper and aluminum.

The methods of mirror reflection and precise focusing of X-rays were used by some investigators to study the formation of substructure in aluminum during its straining at room temperature or during its annealing after straining (Bibl. 14-18). This led to conclusions that substructure forms in the course of plastic flow and not as a result of the polygonization caused by the creeping-over of dislocations. The presence of grain boundaries is conducive to the process of the fragmentation of grains.

Also investigated was the texture in copper, aluminum, pure iron, and siliceous iron with varying contents of silicon (Bibl. 19-24). Siliceous sheet iron with Goss's texture was obtained by Chen Neng-kuan, Tai Li-chi, and their co-workers, and with cubic texture -- by Chou Pan-hsin, Wang Wei-ming and Chen Neng-kuan, who investigated the mechanism of formation of the cubic texture of annealing and advanced the opinion that the theory of the oriented growth of recrystallization nuclei coincides optimally

with their experimental results. Yen Ming-kao and his co-workers (Bibl. 23-24) investigated the recrystallization texture of copper and aluminum. It was found that the sheep copper with ordinary well-known rolling texture yields, after rolling reduction by 90 percent, at low-temperature annealing, textures of (100) [001], (358) [352] and (122) [212], in which connection the grains with orientation of (100) [001] are the first to form. The raising of annealing temperature reduces the number of grains with (358) [352] texture and increases that of grains with (100) [001]-texture. The pure (100) [001]-texture was obtained when annealing temperature reached 900 Centigrade degrees. The above-named investigators suggested that cubic texture is obtained by recrystallization in situ and by selective growth of nuclei. Tai Li-chi and his co-workers (Bibl. 25, 26) investigated the conditions of obtaining cubic texture in 50-percent nickel permalloy.

## 2. Internal Friction and Diffusion

Studies of internal friction in metals and alloys were conducted in connection with many problems such as, among others, diffusion, plastic flow, phase transitions, etc. Of special interest is the work on the internal friction caused by the diffusion of carbon in the face-centered cubic lattice of iron or nickel (Bibl. 28-34). B. N. Finkel'shteyn and K. M. Rozin (Bibl. 27) observed the peak of internal friction in austenitic stainless steel with 25 percent Cr, 20 percent Ni and 0.3 percent C to occur at 300 Centigrade degrees and at the frequency of one cycle per second. This phenomenon was systematically investigated by Ke and his co-workers in 18-8 type stainless steel with 2.6 percent Mo and 0.80 percent Ti, in manganese iron alloys containing from 18.5 to 36 percent Mn, in an iron-manganese-nickel alloy with 12 percent Mn and four percent Ni, and an iron-manganese-nickel-chromium alloy with 9.5 percent Mn, eight percent Ni, and three percent Cr, in pure (99.8-percent) nickel, and in a nickel alloy containing two percent Al, two percent Mn and one percent Si. They proved convincingly that the peak of internal friction in face-centered lattices of austenite or nickel can be observed in the presence of carbon, and that that peak is caused by the micro-diffusion of carbon. The activation energy of carbon diffusion, as calculated on the basis of the temperature-dependence of the peak of internal friction, proved to be the same as the activation energy determined by macroscopic methods; the diffusion constants at 230-250 Centigrade degrees, as determined by the internal friction method, proved to be the same as the diffusion constants determined macroscopically at 1,000-1,200 Centigrade degrees. Further, these investigators found that the height of the peak of internal friction is proportional to carbon content, and that it diminishes very

feebly with increasing manganese content. It is well known that the atoms of carbon occupy the interstices of the lattice of austenite or nickel. In view of the symmetry of interstices in a face-centered cubic lattice, no internal friction should be observed if the atoms of carbon are located one by one in the lattice. To compute the observed peak of internal friction, Ke Ting-sui and Tsien Chih-tsiang (Bibl. 30) suggested that in alloyed steel a carbon atom forms a pair with an atom of the alloying element, and that the peak of internal friction occurs as a result of the re-orientation of that pair because of an applied external stress. In nickel or in low-alloyed steel, a carbon atom forms a pair with a vacant point in the lattice, which yields the same effect as when the vacant point is replaced by an atom of an alloying element.

A different mechanism was suggested by Chen and his co-workers (Bibl. 32, 35, 36). Earlier, Chen Kai-cha had advanced a theory of internal friction based on the general thermodynamic theory of irreversible processes and on Boltzmann's superposition principle. On applying that theory to carbon diffusion in a face-centered cubic lattice, Chen found that the intensity of internal friction should be proportional to the concentration of the carbon introduced into the interstices, and that it should hinge considerably on the content of alloying element. This last conclusion does not coincide with Ke's observations.

Chen showed that here another mechanism may take place, to wit: the carbon atom occupies a vacant point and forms a pair with another carbon atom, located in the interstice nearest the occupied vacancy. The height of the thus created internal-friction peak should be proportional to  $Nc^2/B+c$ , where  $N$  is concentration of vacancies,  $c$  is concentration of atoms in interstices, and  $B$  is a constant. This different mechanism was used by Wu Tsu-liang and Wang Chi-min in interpreting the results of their studies of internal friction in a series of ferronickel alloys containing from 19 to 75 percent nickel. These investigators found that the height of the peak of internal friction increases with increasing carbon content and is proportional to the latter if that content exceeds 0.2 percent. At a given content of carbon, the height of the peak of internal friction increases with increasing nickel content. In an alloy with 50 percent nickel, the height of the peak increases also with increasing temperature of hardening (900-1,000 Centigrade degrees); this effect is to be explained by the influence of the growth in the number of vacancies. In another study (Bibl. 34) Tsien Chi-chiang suggested that the phenomenon of internal friction is a result of the formation of pairs of carbon atoms in interstices.

The internal-friction peak relating to the presence of carbon and an alloying element was observed by Ke and his co-workers (Bibl. 37, 38) also in alloyed martensite. The peak was present at

156 Centigrade degrees and at the frequency of two cycles per second. The investigators concluded that carbon atoms are located in the martensite's lattice in the positions  $(001/2)$ , but, because of the distortions caused by the atoms of the alloying element, and under the action of external stress, a carbon atom shifts its position from that between two iron atoms to that between an iron atom and an atom of the alloying element, thereby creating an internal-friction peak.

Ke and his co-workers (Bibl. 39) showed also in compositions with 0.001-0.017 percent carbon and 0.002-0.03 nitrogen such concentrations of these elements do not affect the diffusion rate. The admixture of manganese (0.23 percent) and silicon (0.13 percent) affects feebly the diffusion of carbon, but it reduces appreciably the diffusion rate of nitrogen. Manganese hastens the segregation of nitrides.

The method of internal friction was applied by Wang Yeh-ning and Chu Chiang Chung (Bibl. 40, 41) in studying martensitic transition in ferromanganese and cuproaluminum alloys. They observed that internal friction increases during direct and reverse martensitic transition; the peak of internal friction vanishes if the transition ceases (if temperature is maintained constant). These investigators conclude that internal friction is created by the interaction between the applied external stress and the inhomogeneities caused by changes in the relative amounts of two phases with different elasticity constants.

### 3. Kinetics of Phase Transitions

Researches in this field have pertained mainly to transitions in steel. Li Lin and her co-workers (Bibl. 42-45) investigated the effect of boron on the hardenability of steel, as depending on the carbon content and austenitization temperature. They found that the increase in hardenability in the presence of boron in chromium-manganese-silicon steel with 0.27 percent C is caused by the prolongation of the period of incubation of hypoeutectoid ferrite and perlite. In hypoeutectoid and eutectoid steel, boron affects feebly the rate of formation of perlite at 650-700 Centigrade degrees; that rate increases with increasing duration of exposure, but during the period after the commencement of transition, a small difference exists in the rates of formation [of pearlite in] steel with boron and steel without boron. The growth rate of perlite within the above-mentioned temperature range doubles in the presence of boron, so that as a result, despite the longer incubation period in the boron-containing steels, the time of ending of transition differs little in the steels with and without boron.

These investigators also observed that in a boron steel with

a sufficiently high content of titanium for fixing nitrogen, the increase in the size of austenite grains caused by the rise in austenitization temperature does not cause an increase in hardenability such as usually takes place in steel without boron. In the steel without titanium, an increase in hardening temperature reduces the hardenability of boron steel until 1,200 Centigrade degrees, when the hardenability proves to be the same for boron steel and for steel without boron. This indicates that the presence of boron reduces the role of the surface energy of grain boundaries in the formation of pearlite. The nature of carbides in alloyed steels and of their transition has been intensively studied by Ko Ke-hsin (Bibl. 46, 47).

The distribution of alloying elements in pearlite during its formation in alloyed steel was investigated by Chang Pei-lin and his co-workers (Bibl. 48) in chromium steels. They observed that the type and composition of the carbides initially forming during pearlitic transition depend on the mutual ratio of the concentrations of chromium and carbon in the austenite and are not determined by the structural diagram. If the atomic ratio of Cr:C equals 2:1 then cementite initially segregates from the austenite; if this ratio changes from 2:1 to 13:1 then it is  $(\text{Cr, Fe})_4\text{C}$  [one sign is illegible] that segregates out; if this ratio exceeds 13:1, then it is  $(\text{Cr, Fe})_{23}\text{C}_6$  that segregates out.

Ko Tsun, continuing his work on the mechanism of bainitic transition, proved together with his co-workers (Bibl. 49, 50) that the well-known Widmanstatten structure of alpha iron in a coarse-grained hypoeutectoid carbon steel forms through bainitic transition; during the transition the carbon diffuses from bainite into austenite. Further, they showed that bainitic transition can occur between points  $A_1$  and  $A_3$ .

Tsi Tseng-fon observed that in 55-S-2 steel the bainitic transition accelerates in the presence of small amounts of martensite and slows down if the amount of martensite becomes large (Bibl. 51).

The mechanism of the transition of residual austenite in quick-cutting steel into martensite after tempering at 500-560 Centigrade degrees was studied by Ko Tsun, Hsu Tsu-yao and their colleagues at Peking Institute of Ferrous Metallurgy. Ko opined that the "conditioning," i. e., the transition of the residual austenite of quick-cutting steel after tempering, is a reverse effect of mechanical and thermal stabilization occurring during the initial period of the formation of martensite. Ko Tsun and Chen Meng-tse (Bibl. 52) showed that the transition into martensite after tempering can be averted by stabilizing treatment at a temperature a little above that at which the austenite passes over into martensite without such treatment. However, the effect



of the stabilization may be forfeited if the steel is again heated to tempering temperature. Such a process may be repeated seven times.

Hsu and others (Bibl. 53-55) subsequently showed that the residual austenite in quick-cutting steel has a critical temperature above which the "conditioning" or destabilization occurs, and below which stabilization occurs, and that both these processes are mutually inverse.

Chang Pei-lin and Chu Sui-chang investigated the nature of residual austenite of hardened ball-bearing steel below the  $M_s$ -point and ascertained that an isothermal transition of the residual austenite into martensite takes place (Bibl. 56).

The amount of residual austenite in high-strength structural steels increases with increasing size of the elements fabricated from such steels, as a result of the stabilization effect caused by the decrease in cooling rate. The austenite passes over into martensite during the operation period, and causes the brittleness of the steel. Sze Chang-hsu (Bibl. 57) found that silicon (1.5 percent) reduces appreciably the rate of disintegration of austenite in low-carbon high-strength steel when tempered at temperatures ranging from 100 to 400 degrees.

Chou Chih-hung continued his studies of the martensitic structure of iron and iron-carbon alloys and related the nature and mechanism of martensitic and bainitic transitions to the mechanism of formation of the Widmanstätten structure (Bibl. 58).

The disintegration of delta-ferrite in stainless molybdenum and titanium steels was investigated by Chuang Yu-chi and his co-workers (Bibl. 59-61). They systematically studied the mechanism of disintegration and the products of disintegration at various temperatures (500-950 Centigrade degrees). The kinetics of the processes of ordering and disordering was investigated by Sze Shih-yuan and his co-workers (Bibl. 62-64). They concluded that the formation of antiphase domains is a process of formation and growth carried out by the diffusion of vacant lattice points.

The rate of rearrangement of atoms from disordered into ordered state hinges on two opposed factors: rate of diffusion and the difference in the free energy of two phases, which is

proportional to  $\frac{1}{T} - \frac{1}{T_0}$  where  $T_0$  is Curie's ordering

temperature. These investigators proved experimentally the existence of a temperature at which the rate of transition is maximal, as could be concluded from their theory.

#### 4. Theory of Metals and Alloys

During their studies of the conditions of phase formation in ternary systems, Lu Hsueh-shan and Chang Tsung (Bibl. 65) observed that in an Al-Cu-Ni system the  $\theta$ -phase undergoes systematic structural changes in the single-phase range contrary to the customary representations about the intermetallic phase as one characterized by a definite type of crystal structure. In the given case, these investigators observed structures of the defective lattice type, each of which can be constructed on the basis of the rhombohedral unit of the structure. On the basis of an Hume-Rothery evaluation of valence, it can be assumed that the mean number of valence electrons in a structure unit remains constant throughout the entire single-phase range, whereas electron concentration varies with composition. These investigators assume that in alloys in which the unit cell does not change, the mean number of electrons in a structure unit is equivalent to the number of electrons in the unit cell, and that for the intermetallic phase without defects it is actually equivalent to electron concentration. During their studies of alloys of the silver-gold-zinc system with 50 percent zinc, Liu Yi-huan (Bibl. 66) and his co-workers had observed the phase of  $\text{AgAuZn}_2$ ; they found that that phase has the same structure as that of Heusler's alloys.

The intermediate phases in variants of the above system containing from 0 to 50 percent gold, follow when forming the Hume-Rothery rule.

Chang Chung-sui, Wang T'ieh-mu and Su Hong-chang (Bibl. 67, 68) conducted investigations of the statistical theory of solid solutions. A new method was offered for determining the configurational free energy of solid solutions. This method is simpler, more reliable and at the same time more broadly applicable than the previous methods. This new method was applied to cases of the formation of a superlattice in a face-centered cubic lattice; the change in the degree of ordering and the latent heat of solid solutions were calculated.

In his investigations of the theory of crystal-lattice spectra Chen Kai-cha (Bibl. 69) obtained a general proof of the postulate of the possibility of representing upper Brillouin zones by means of a transposition of zone fragments. He showed that that postulate should be made more precise in the following manner. All upper Brillouin zones can be accurately represented in the first Brillouin zone by means of a definite subdivision of zone fragments and their appropriate transposition. The Thomas-Fermi and Slater methods were utilized by Chen Kai-cha (Bibl. 70) for calculating the binding energy and interatomic distance in metals, and for concluding that the electron on the surface of sphere in Seitz's cell method receives on the whole a potential energy equal to  $-e^2/R$  and

not to zero as Slater and Kratter (Bibl. 71) had suggested. At such a boundary condition, the total energy determined by numerical integration as a function of interatomic distance has a minimum -- a result which could not be obtained in the calculations done according to Slater and Kratter. The computed interatomic distances coincide satisfactorily with those observed for polyvalent heavy elements, but not with those for monovalent light elements.

As can be seen from the foregoing brief survey, the few years elapsed since the birth of the Chinese People's Republic have been marked by a rapid development of the physics of metals and physical metallography, the pace of which has become even more fervid after the Great Leap Forward in 1958. It is to be pointed out that this quick progress could not have been feasible without the assistance of the Soviet people. A great number of [Chinese] metals physicists and metallographers has been trained in Soviet universities, higher schools and scientific-research institutes. Many Soviet scientific research workers, such as Professors V. D. Sadovskiy, B. G. Livshits, M. G. Morozov, and L. I. Vasil'yev, in the last few years have toured China and given a great number of scientific lectures and lessons. All this had a pronounced effect on the course of the accelerated development of science.

There arose a new generation of metal physicists and metallographers, and the basis for a further rapid development was created.

Chinese People's Republic

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